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Evaluation of Gelabar Earth Dam Behavior during Construction and First Watering by the Method of Limited Components and Comparison with Real Amount Resulted by Precise Instruments Data

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Abstract

The increase in pore water pressure in earth-rock fill dams with clay core during construction and first watering can cause the start and progress in hydraulic fracture. Construction costs being high and also the damage caused by dams' fracture make the necessity of taking care and behavior survey of earth dams, more obvious than anything. According to this, in this research while modeling Gelabar earth dam, pore water pressure, pore water pressure ratio, the amount of total stress and effective stress, arching and lateral soil pressure ratio is measured and has been compared with the amount measured by precise instruments which has the construction capability of Plaxis v8.5 for numerical modeling from two –dimensioned software, has been used. Behavior models used in this analysis, Moher- Coulomb and it is xis v8 hardening. Considering the data of precise instruments installed on Dam's body and implementing return analysis, real parameters of construction materials was obtained. Evaluation of numerical modeling results and precise instruments can find out an appropriate Dam behavior and consequently, the correct modeling procedure. Also, studies have been indicator of suitable stability and safe position for Gelabar Dam.

Keywords: Gelabar Dam, Precise instruments, Numerical Analysis, Pore water pressure, Total stress, Effective stress, Arching

Introduction

Earth dam development has caused that most dams in the world to be of earth – rock fill type. In the past, for the lack of knowledge from these dams' behavior, the height of earth dams were limited, but today, by the development of soil mechanics science and the existence of advanced soft wares for the modeling and analysis of earth dams, the height of theses dams has been increased. Among high earth dams in the world, Roguni Dam with the height of 335 meters 1 can be mentioned which is located in Russia (Saeedi Nia , Akbari, and Salemi, 2012). Considering high cost of construction of Dams and extensive damages caused by their unsafety, dams' sustainability control is of great importance. In order to evaluate Dam's behavior, Return analysis method can be utilized. In this method, Dam performance has been measured through the assessment of results obtained from precise instruments used on Dam's body, is evaluated. For Dam's behavior logy, the results obtained by precise instruments are compared with preliminary suppositions related to Dam design. Earth Dams having various parts include: core, crust, filter, drainage, Rock-fill cover (Rip Rap). In these types of dams sealing is done by core. Dam core can be constructed by construction materials with low penetration like: Clay and Concrete that because of appropriate flexibility of Clay and it is being economic, in most Earth dams clay has been used for the core construction. In these dams because the lack of penetration in construction materials of the core, the increase in dam reservoir balance in preliminary watering period causes the rise in pore water pressure on the core. By The increase in pure water pressures the effective stress between sand particles decreases that this issue causes soil shear and the increase of the risk of Dam hydraulic rupture. Therefore, created pore water pressure control during preliminary watering period, plays a significant role in dam's stability. Also, the control of existing stress on dam's body and comparing it with the amounts considered in preliminary dam design is of great importance in conservation of dam's stability. Maleki and Alavifar (2005), have evaluated behavior of Masjed Soleiman 's Dam along with numerical analysis through FLAC 4.0 software. Parameters; pore water pressure ratio ,have expressed and determined arching and the amount of changes in total stress and transformations due to first watering of Dam's reservoir , can threaten Dam's stability. Mirghassemi and Mokrami Ghartavol (2013) by using piezometers' results and applied stress testers in clay core of Gelabar Dam, have evaluated Dam's status during construction and return analysis have been implemented by ABAQUS software, finally they have expressed that the amounts of pore water pressure in core during construction of Dam, total stress changes and effective stress have been at acceptable range. Niroumand et al (2000) have evaluated and expressed the function of Karkhe Dam, which is considered one of the largest earth dams in Iran, by using the results of precise instruments and return analysis have been implemented through CA2 software that regarding measured vertical pressure, there is a great conformity among the results obtained from precise instruments and the software. Aflaki (2009) evaluated Shirin Darreh earth dam and expressed that regarding Dam subsidence and total stress ,there is a relatively great conformity among the result of software, stress testers and subsidence testers. Nik-khah in the year 2007[8], evaluated the precise instrument installed on Molla Sadra earth Dam's body and considering the rate Arching ratio which was between 0.45 to 0.58, he expressed that Molla Sadra Dam is at suitable condition. Cherzanovski et al (2002) have evaluated the parameters of earth dam's construction materials, at Diamond Lake and valley, based on geodesy measurement and provided a method of using limited element analysis, for modeling the impact of dam construction materials saturation in order to determine and change sites during reservoir watering.

In the present research return numerical analysis have been implemented and main parameters of construction materials have been specified and then they studied the pore water pressure, pore water pressure ratio, the amount of total stress and effective stress, Arching, soil lateral pressure ratio (Malaei, 2014).

Materials and methods

General features of Gelabar Dam

Gelabar Earth- Rock fill dam is locate at Zanjan, 50 kms south –west Ejroud Sub-province and 3kms to Gelabar village and on Sajass River, which is at the moment the largest dam in the province. The maximum height of the Dam; from bed rock 82 meters (from level 1628 to 1710) and the dam crest height is, 247 meters. Utilizing this Dam, has made 8 acres of rain fed lands of Ejeroud sub-province have become watered land and in addition, it supplies the water for industries such as petrochemicals. This dam has been constructed with the objective of Sajs roud flood control, agricultural, industrial and services water supply , increase of agricultural products , lateral industries and creating jobs. Utilizing this Dam, 46 million cube meters of water supply for agricultural lands and sub-province's industries have been regulated by this dam. Gelabar Dam , has been instrumented in 8 sections and the applied types of precise instruments on dam's body are as follows:

47 Electronic Piezometers of vibrating web(EP), 34 vertical pipe piezometers, and observation wells on rest points(P).

69 Soil pressure measuring tools, including Quintuplet clusters (PC). Inequality testers and the plate levels of subsidence testers are in 8 transverse sections of the Dam, 5-5 section is the middle section and the most highest and full of instruments, in Gelabar Dam. The mentioned section

is analyzed as the maximum and most critical section (figure 1),and also(figure 2) shows the General plan of Gelabar Dam.

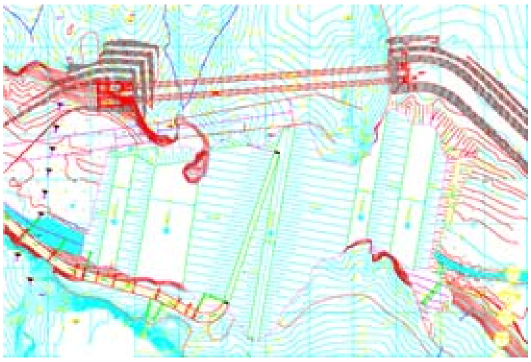

Figure 1. Section 5-5 Gelabar Dam

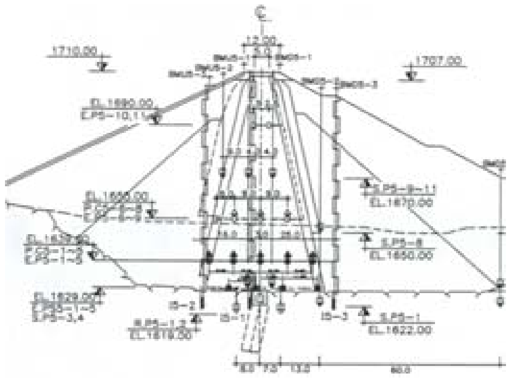

Figure 2. General Plan of Gelabar Dam

Modeling steps for Gelabar Dam and the implementation of return analysis

The main objective of applying return analysis, is to achieve to more precise features of containing construction materials of the Dam and the closeness of model behavior to the real dam behavior. Comparing the results of precise instruments and numerical model can achieve the parameters which makes the model behavior close to the reality. In Gelabar Dam before return analysis ,the accuracy of the precise instruments' results has been evaluated and considering the evaluations implemented ,Dam's existing condition was determined that installed piezometers at level 1690,because of the low embankment on them and also piezometers at level 1655 because soil unsaturation until day 280 of Dam construction , and the piezometers installed at level 1629 located at lower hand of the core ,do not show correct function.

PLAXIS V8.5 software is used for modeling analysis. This software has been written based on the limited components relationships that are able to analyze stress- transformation and stability of geotechnical structures in plain strain status and also calculation of water flow in these types of structures (Brinkgreve and Vermeer, 2001).

Two below models are used in Gelabar dam analysis:

A - Moher- Coulomb Model

This model is used in many researches because of simplicity and no need for numerous parameters. The concept of plasticity is mainly related to irreversible strains. For this reason a subordinate of stress-strain surrender is introduced as a level in main stress environment so that plastic points can be evaluated. It is obvious that some points in surrender level have a complete flexible behavior. Based on this model, strain and the rate of strain are comprised of two parts of elastic and plastic. In other words,

$$\underline{\dot{\sigma}}^e = \underline{\underline{D}}^e \, \underline{\dot{\varepsilon}}^e = \underline{\underline{D}}^e(\dot{\varepsilon} - \dot{\varepsilon}^P) \tag{1}$$

According to plasticity theory (Hill,1950), plastic strains are in the proportion of derivation of surrender function towards stresses. In other words, plastic strains can be considered as vectors vertical to surrender level. Based on this , the relationship between the rate of effective stress and the rate of effective strain can be obtained.

$$\underline{\acute{\sigma}} = \left(\underline{\underline{D}}^e - \frac{\alpha}{d}\, \underline{\underline{D}}^e \, \frac{\partial g}{\partial \underline{\acute{\sigma}}} \, \frac{\partial f^T}{\partial \underline{\acute{\sigma}}} \, \underline{\underline{D}}^e\right) \underline{\dot{\varepsilon}} \tag{2}$$

In this equation d = $\frac{\partial g}{\partial \underline{\acute{\sigma}}} \underline{\underline{D}}^{e} \frac{\partial f^{T}}{\partial \underline{\acute{\sigma}}}$. Moher- Coulomb surrender standard has been according to main stresses and comprises of a hexahedron cone in major stress environment can be shown as general equation;

$$f_{(i,j,k)} = \frac{1}{2}\left|\left[\acute{\sigma}_{(j,k,i)} - \acute{\sigma}_{(k,i,j)}\right]\right| + \frac{1}{2}\left|\left[\acute{\sigma}_{(j,k,i)} + \acute{\sigma}_{(k,i,j)}\right]\right| \sin\emptyset - c \cos\emptyset \leq 0 \quad (3)$$

In which k,j and i respectively are 2,3 and 1. Two parameters of $\emptyset$ and C in this model are adherence and soil fraction degree. Also, six potential function of plastic can be defined and the general equation below:

$$g_{(i,j,k)} = \frac{1}{2}\left|\left[\acute{\sigma}_{(j,k,i)} - \acute{\sigma}_{(k,i,j)}\right]\right| + \frac{1}{2}\left|\left[\acute{\sigma}_{(j,k,i)} + \acute{\sigma}_{(k,i,j)}\right]\right| \sin\Psi \leq 0 \quad (4)$$

Ψ parameter has been the dilatation angle which with its aid volume strain of saturated soils, can be modeled.

B - Hardening model

In hardening behavioral model, the surrender level in major stress environment has not been limited and because of the existence of plastic strains, the below level is developed. In this model there are two hardening shear and compressive stresses which are respectively applied for modeling the strains of non –flexible plastics of comprehensive deviated stress and pressured stress. Also, this model has an application for the simulation of soft and hard soils. When the soil is under deviated stress, the soil hardness has been decreased and plastic strains are developed. This kind of behavior is capable of modeling through hyperbolic model (Duncan and Chang,1970). Hardening model because of utilizing plasticity theory and entering dilatation parameters and also soil hardness to stress and strain is more appropriate alternative. One of features of this model is dependence of soil hardness to stress which in consolidation conditions is expressible as below:

$$E_{oed} = E_{oed}^{ref}\left(\sigma/P^{ref}\right)^{m} \quad (5)$$

For the soft soils supposed that m=1 is close to reality. In this case

$$E_{oed}^{ref} = P^{ref} / \lambda^{*} \quad (6)$$

$$\lambda^{*} = \lambda/(1+e_0) \quad (7)$$

In these equations P^{ref} is reference stress and λ^{*} is modified compaction index. In a similar type, flexibility ratio of unloading and reloading can be related to modified inflation ratio K^{*} , in other words

$$E_{ur}^{ref} = 3P^{ref}(1-2\upsilon_{ur})/K^{*} \quad (8)$$

$$K^{*} = K/(1+e_0) \quad (9)$$

In which υ_{ur} is Poisson ratio of unloading and reloading. In this model the impact of soil movement or secondary subsidence that mainly occurs in long –term, is not considered.

Hardening soil model is an advanced model for soil behavior simulation. for Mouher – Coulomb model the limited stress status is described through fraction angle Φ and adherence c and dilatation angle Ψ ,while that in hardening model ,the soil hardness is described more accurately by using three different inputs , three axis loading E50 ,hardness of three axis unloading Eur and hardness of audio meter loading , the main difference in Mouher- Coulomb model and hardening soil is that hardening soil model is subordinate to stress, and has considered hardness. This means all hard nesses increase with pressure. Therefore, each three hard nesses affiliated to reference stress are considered 100 kpa. Summary of modeling procedures are this way that after implementation of Plaxis Program and applying required preliminary adjustments, model geometry is drawn precisely and by using standard fixities selection, defined constraints and after this stage, construction material features of each cluster, considering tables 1 and 2 in preliminary analysis and table 3 in return analysis are defined. More to that, meshing operation has been done and after definition of preliminary water level , we enter measurement stage that in model related to Gelabar Dam, include sixteen different construction stages that are respectively are evaluated.

First measurement stage is related to conditions Dam site during excavation and the second measurement stage is of status where embankments around dam has been constructed and the first layer of dam body is also constructed. The Dam body embankment stages of third to seventh stage are evaluated layer by layer. Seventh stage up to next is related to the period of first dam reservoir watering. Gelabar Dam watering has started on Aug, 2006 and the reservoir water level has reached a relatively fixed level [4]. Different kinds of calculations are listed in Calculation type section that considering the type of required calculation, one of them is selected. Plastic type is for the status that there is no need to consider the time in calculations and this type of calculations is used in most Geotechnical issues. Consolidation type is for condition where it is required that Consolidation in Model to be considered. In this type the loading measurement is done in stages. Selecting this type of calculation, software through stage loading evaluates the consolidation phenomenon in model. Ph/ic reduction is for the calculation of dam's reliability ratio for stability. In this method soil parameters (tan f and c) are regularly decreased so that the soil is raptured. In present model for first and second phase , calculation type is plastic and for other phases except last phase consolidation calculation type is supposed. In only last phase that deals with the determining relaibility level against stability. Type of calculation is Ph/ic reduction.

After the completion of calculation operation, at the top of the page, output option is appeared. To see the output of each phase, first we select it and then we click on out put option. In output page using existing options in menu at the top of the page, all information regarding stress, obeisance, pore water pressure, water flow line, and dam body subsidence can be obtained. Next , as a sample is mentioned , related to pore water pressure is created in cross section of Gelabar dam (Malaei, 2014).

After preliminary analysis, main and first input parameters should be changed logically to software like elasticity and penetration module considering Dam's real behavior, so that the real behavior is also created in model. Pore pressure is of important issues in soil mechanics engineering. Changes in pore pressure ratio in earth dams at construction time, depends on factors such as: overhead pressure, the speed of embankment, drainage speed, penetration, saturation degree and soil density. The increase in pore pressure has caused soil shear resistance and it threatens dam stability. Therefore, by controlling embankment speed, pore pressure speed can be controlled. Through increase of elasticity module, the soil becomes harder and its density is increased, this matter causes the soil mass become less dense and smaller values of is transferred to existing liquid phase and it causes the amounts of extra pore water pressure on soil. Also by decrease in penetration, the amounts of water created in pore pressure, will be more. Another effective parameter in modeling is the percentage of soil density (Niroomand, 1996). The more the percentage of soil density is, the more the created pore pressure will be. Since, the embankment density in Dams such as Gelabar Dam with high density percentage and close to 90% is applied and this amount increases by continuing embankment till the complete saturation. In numerical model, the dense soil has been supposed saturated form the beginning. It is worth –mentioning that the penetration of dam foundation at contact place with core has been improved by cement slurry injection (Consolidation Injection). Therefore, in numerical model also in order to reset parameters, foundation penetration has been decreased.

The features of construction materials comprising Gelabar Dam that includes five main sections: Clay Core, Filter, Crust (Sand), Crust (Land-fill) and foundation, include: table (1) related to the amounts of main and first parameters based on Mouher- Coulomb and table (2)related to the amounts of main and first parameters is regarding hardening behavior and resulted parameters of return analysis and reset is expressed in table 3

Table 1. Geotechnical Parameters of applied construction materials in Gelebar Dam , Mouher Coulomb modele

e_o	k (m/sec)	n	F	C (Kpa)	E (Mpa)	gd (t/m2)	Construction material features
0.54	1E-9	0.3	27	10	25	1.7	Clay Core
0.18	1E-5	0.3	35	0	28	2.0	Filter
0.18	1E-5	0.3	42	0	40	2.0	Crust (sand)
0.11	1E-5	0.3	46	0	54	22	Crust(rock- fill)
0.25	1E-7	0.24	36	100	150	23	Foundation

Table 2. Geotechnical Parameters of applied construction materials in Gelebar Dam, hardening model

Eref50 (MPA)	Erefoed (MPA)	Erefur (MPA)	Construction material features
27.50	32.07	85.95	Clay Core
30.80	35.92	96.26	Filter
165.00	192.45	515.70	Foundation
44.00	48.96	137.52	Crust (sand)
50.40	66.52	185.65	Crust(rock- fill)

Table 3. Geotechnical parameters of Gelabar Dam(the amounts used in return analysis).

e o	k (m/sec)	n	F	C (Kpa)	E (Mpa)	gd (t/m2)	Construction material features
0.54	5.7E-10	0.3	27	15	17.8	1.7	Clay Core
0.18	1E-5	0.3	35	0	28	2.0	Filter
0.18	1E-5	0.3	42	0	40	2.0	Crust (sand)
0.11	1E-5	0.3	46	0	54	22	Crust(rock- fill)
0.25	1.58E-8	0.24	36	100	150	23	Foundation

Evaluation of pore water pressure

A set of piezometers cross- section 5-5 include: four piezometers at level 1629, 5 piezometers at level 1639, four piezometers at level 1655 and two piezometers at level 1690 that precise instruments readings from the first day of installation till the day 2020 is registered and in access. It is worth- mentioning that Gelabar dam's lake watering from the day 428 of construction has been started.

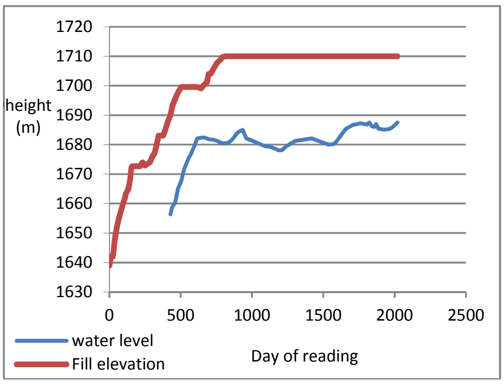

Figure 3. Gelabar dam Embankment level and watering

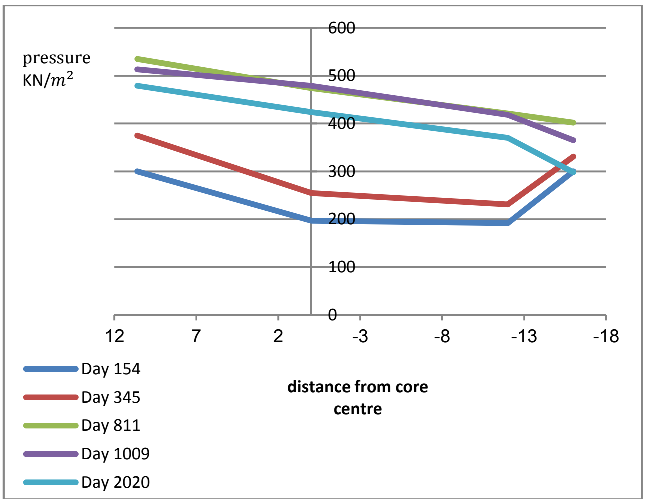

Figure 4. Changes in pore water pressure, level 1629.

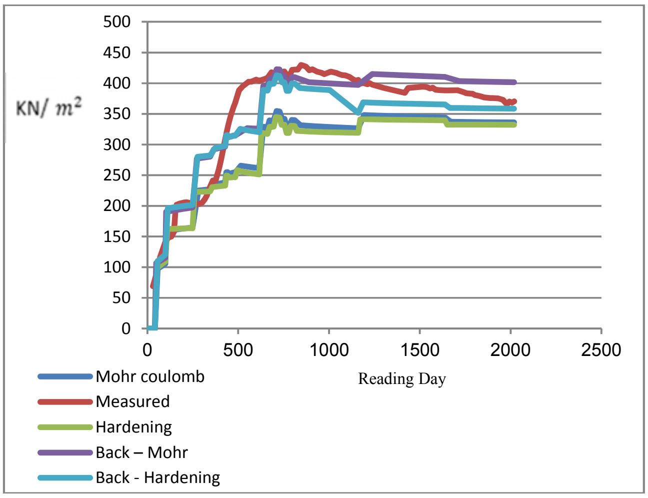

Figure 5. Piezometer function, level 1629, lower hand the core .

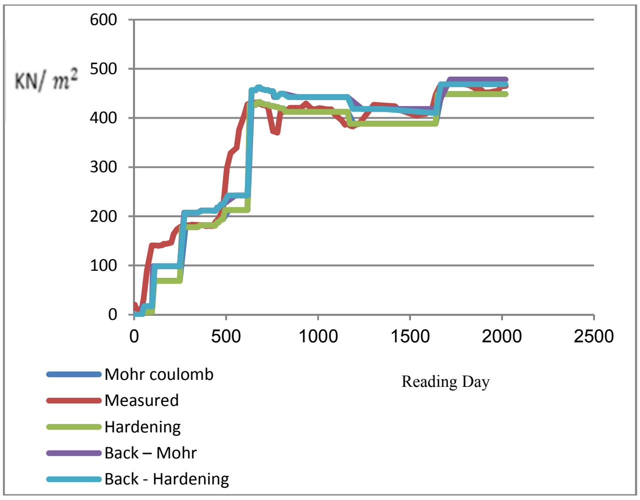

Figure 6 . Piezometer level 1639, upper hand filter

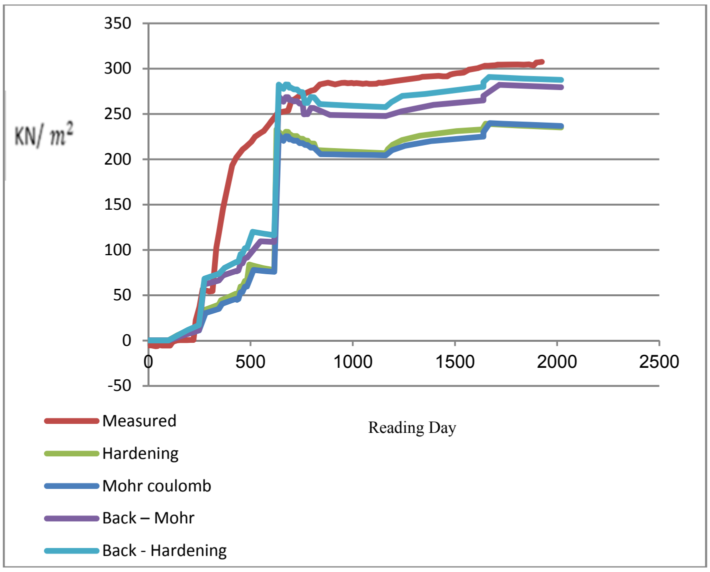

Figure 7. Piezometer, level 1655, upper hand the core

The results of software results along with the results obtained from precise instruments in order to evaluate the correctness of dam‘s function during construction and first watering, in figure 3-7, have been compared and the figure 3 has showed the embankment procedure and Dam’s watering during construction and its first watering .

Studies show that the pore water pressure during construction increases by the increase in embankment level and by starting dam watering and reaching the water level to the piezometers and water level getting higher at upper and of the Dam, piezometers show more pore water pressure, of course the Piezometer installed upper hand of the core affects more from upper hand water level and when we move down from upper hand to the lower hand, the rate of impacting becomes less and the time of impacting becomes more, its reason is also the low penetration of construction material of the core , of course after watering and through the passage of time the pore water pressure Figure ,comes out ascending status and it follows a descending procedure for some time, that the reason for this is the consolidation phenomenon. Results obtained from modeling based on the preliminary construction materials’ features show that, precise instruments show more pore water pressure but in return analysis done, through the decrease of foundation penetration because of consolidation injection operation at the place of connection of dam’s body to the foundation by cement slurry and the change in effective parameters, the curve of changes in model has had more proportionate function with precise instruments. Also reviews show , installed piezometers at level 1690 lower hand and upper hand of the core for the low embankment(maximum 20 m), show ineligible amounts for pore water pressure which these data are not attributable.

Evaluation of changes in general and effective changes

Set of tools in 5-5 cross- section

Cross –section 5-5, level 1639, has five Total Pressure Cells (TPC) and at level 1655 has 3 TPCs has been installed that each TPC includes five tester in different directions and a piezometer.

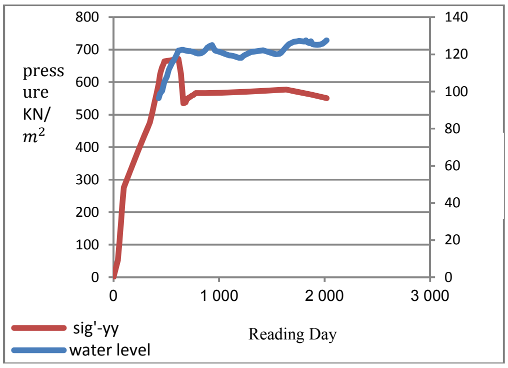

Figure 8. Effective stress, level 1639, core upper head, P.W Axis 90

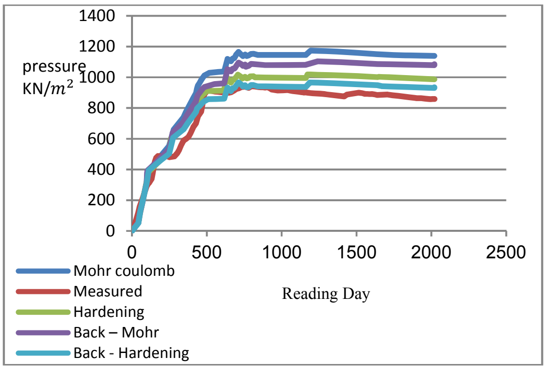

Figure 9. Total stress, level 1639, lower hand the core, FLAT

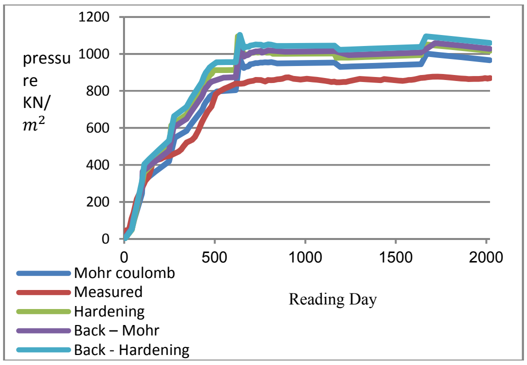

Figure 10. Total stress, level 1639, upper hand filter to DS to - 45

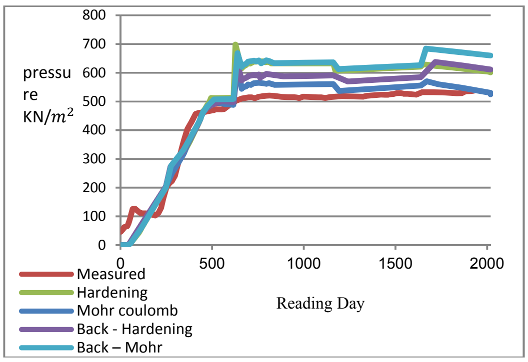

Figure 11. Total stress, level 1655, upper hand the core , V to axis- 90

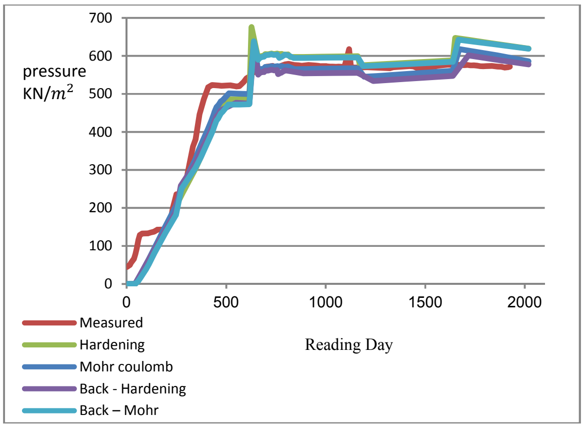

Figure 12. The stress of total level 1655, upper hand the core, to RS -45

The review of stress testers shows that total stresses obtained from return modeling in x,y,z directions have relatively great conformity with the results of precise instruments and in final reading days because of consolidation phenomenon, total changes procedure of total stress, has had the descending process to the small amount and also as observed in Figure (6),by the increase in embankment level ,effective stress increases, but by the start of watering the lake and the increase in dam reservoir water level, the effective stress decreases and at the final days ,because of consolidation phenomenon descends.

Review of the installed stress testers by 45 degree, shows that the measured amounts is less than the amounts of return analysis that is likely the reason for this difference in method and installation stages of precise instruments.

For installation of pressure – tester cells at a specified level, they excavate a hole at the considered area and locate pressure –tester in the hole and then fill out the excavated hole with the same construction materials and smash it again, but considering that the soil to fill the hole excavated, is going to be dense by lighter rollers, always the existing soil in the hole is less dense than the soil surrounding the hole and by the increase in Embankment level, soil construction materials existing inside the hole rely on the surrounding and as a result , local Archingoccurs and following that the registered stress through precise instruments , makes error. Also, the error existence at placement angle precisely or change of angle during soil density by the rollers or later stages dam embankments causes error in angled precise instruments.

As it can be observed , in return analysis ,the Figure procedure relies on hardening behavior has better conformity with precise instruments than Mouher- Coulomb behavior. The reason for this is that hardening model because of considering more parameters of the soil, models construction material behavior better than others. In this model surrender level is larger because of plastic obeisance (despite Mouher- Coulomb behavior). On the other hand, in hardening model soil dilatation has been seen during the cut. This issue is more important for the lower layers that gradually through embankment procedure development consolidate. In other words, elasto –plastic model, models soil behavior in ordinary flexible stresses, thus in hardening model the soil behavior is considered elasto – plastic from the beginning.

Results show that major changes in dam's body has occurred during construction operation, this problem reveals the necessity of behavior assessment during construction.

Set of Cross- section instruments 3-3 and 7-7

3-3 Section has three TPC cells installed at level 1655 and also section 7-7 has three TPC. cells installed at level 1657 meters, locating features of the above –mentioned instruments include: lower hand set of instruments that are at the distance , 9 meters from the core center (PC3 -1- 5 and

PC3-1-1), set of instruments installed at the center of the core (PC3-2-5 and PC3-2-1) and set of instruments installed at 9 meters distance from the core center (PC3-3-5 and PC3-3-1). It is worth-mentioning that for views of installed tension gauges , three numbers are used that the first number from the left side is indicator of installation section , the second number from the left side , lateral location of precise instruments(the lateral distance of precise instrument installation from the core center) and the third from the left side is indicator of of installation status of tension gauge that RS=1to -45 , V to axis- 90 , FLAT= 3, P.W Axis 90, DS to – 45 ,

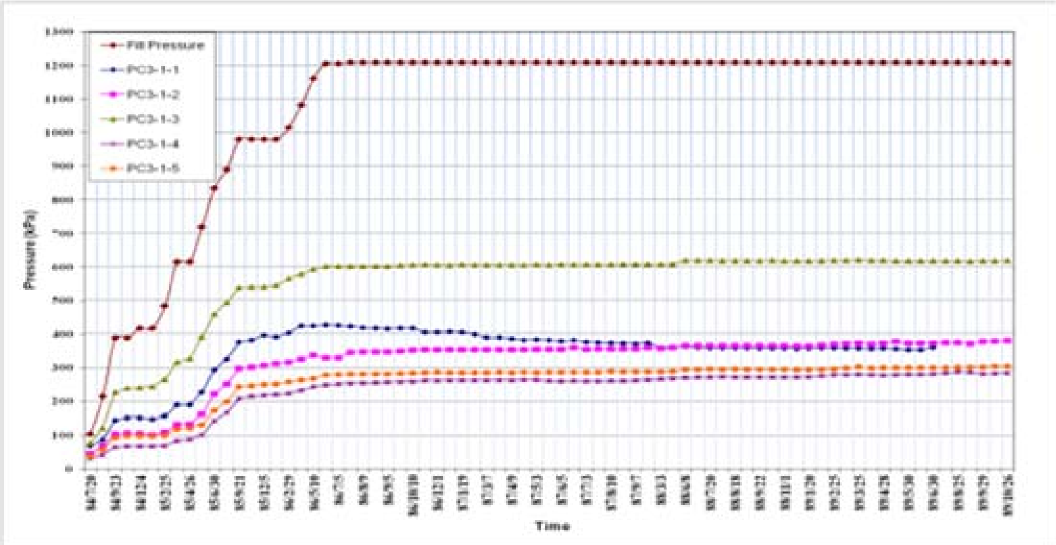

Figure 13. Total tension, section 3-3, level 1655, lower hand the core

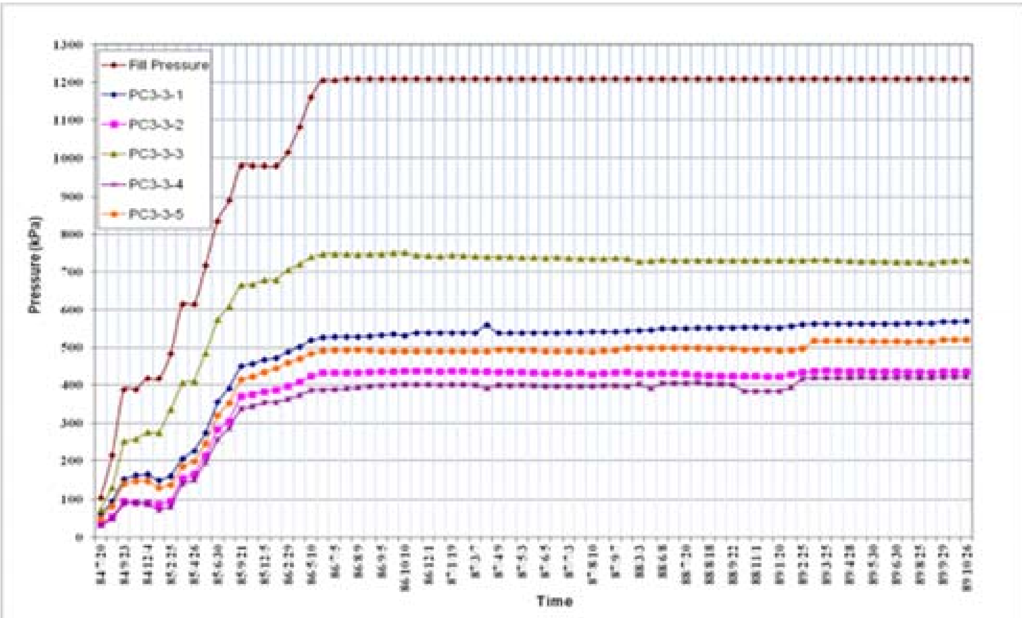

Figure 14. Total tension , section 3-3 , level 1655, upper hand the core

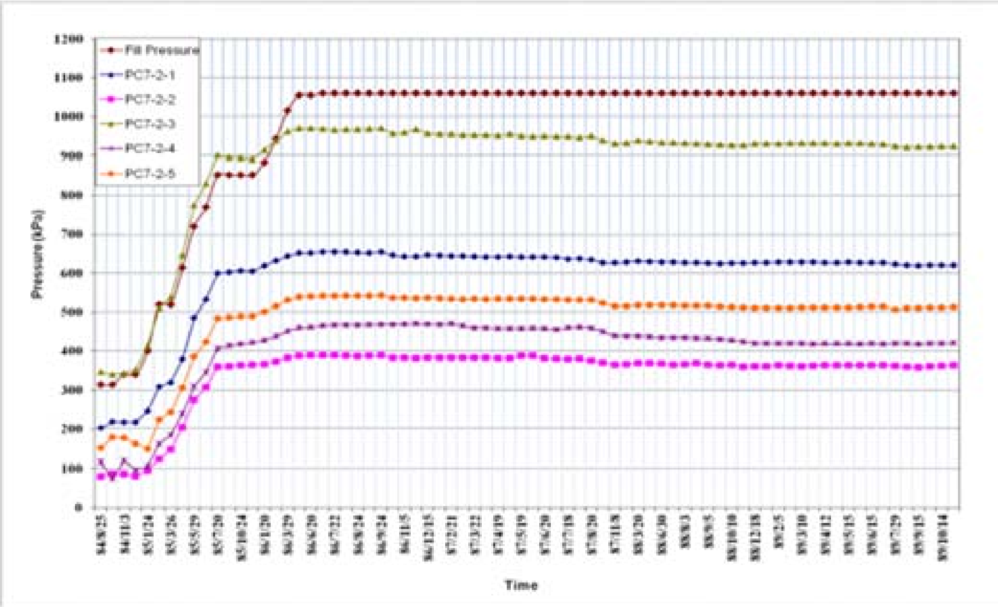

Figure 15. Total tension section7-7,level 1657, core center

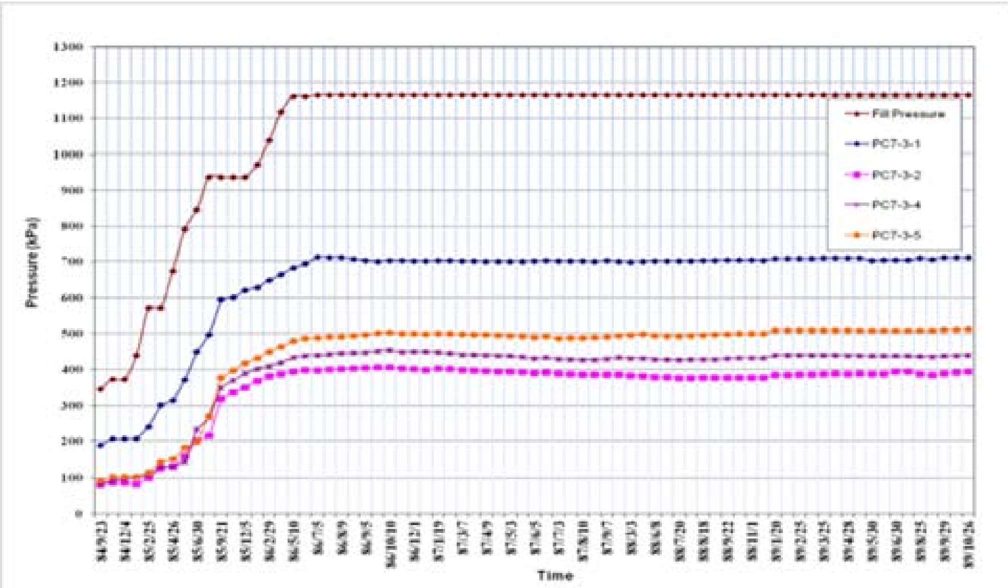

Figure 16. Total tension,section7-7, level 1657, upper hand the core

Review of above figures show that in proportion with the increase in embankment level, the amount of total tension starts to increase, but after completion embankment operation through the passage of time and applying consolidation phenomenon, ascending process of total tension Figure is decreased and finally also slightly descends. With a little attention, we find out that if we make comparison among five tension gauges at one point , this conclusion is reached that maximum amounts of tension directions are respectively as follow: FLAT, RS to -45, DS to- 45, PW Axis-90 and V.to Axis -90.

Reviewing the related figures of section 3-3 ,we found out that the rate of total tension at a specified level ,considering the distance of precise instrument's distance from the lake varies, as with the comparison of three points upper hand the dam (+9 meters), the core center and lower hand of the dam (-9 meters),we found out that the maximum total tension is related to the tension gauge installed at upper hand of the dam that by moving towards the core , the amount of total tension is decreasing but passing the center of the core and nearing the lower hand of the dam ,the amount of total tension is increased but still it is less than the total tension amount at the upper hand of the dam.

Evaluation of pore water pressure ratio

The created pore water pressure inside the core has a significant role in Dam's stability. In order to make the obtained results more comparable, precise instruments and software in Gelabar Dam and other Dams are used in order to calculate pore water pressure as the proportion of RU. To evaluate pore water pressures inside the core, determining the pore pressure is of especial importance. The pore pressure of a point of the core is equal to the proportion of calculated pore pressure inside the core on total measured vertical pressure at that point (equation 8). Low pore water pressure is indicator of high dam reliability ratio against hydraulic rapture.

$$Ru = \frac{u}{\gamma\, h}$$

Gelabar dam has 8 cross –sections that have piezometers installed at different levels. Following that, the Figures related to different sections, is provided.

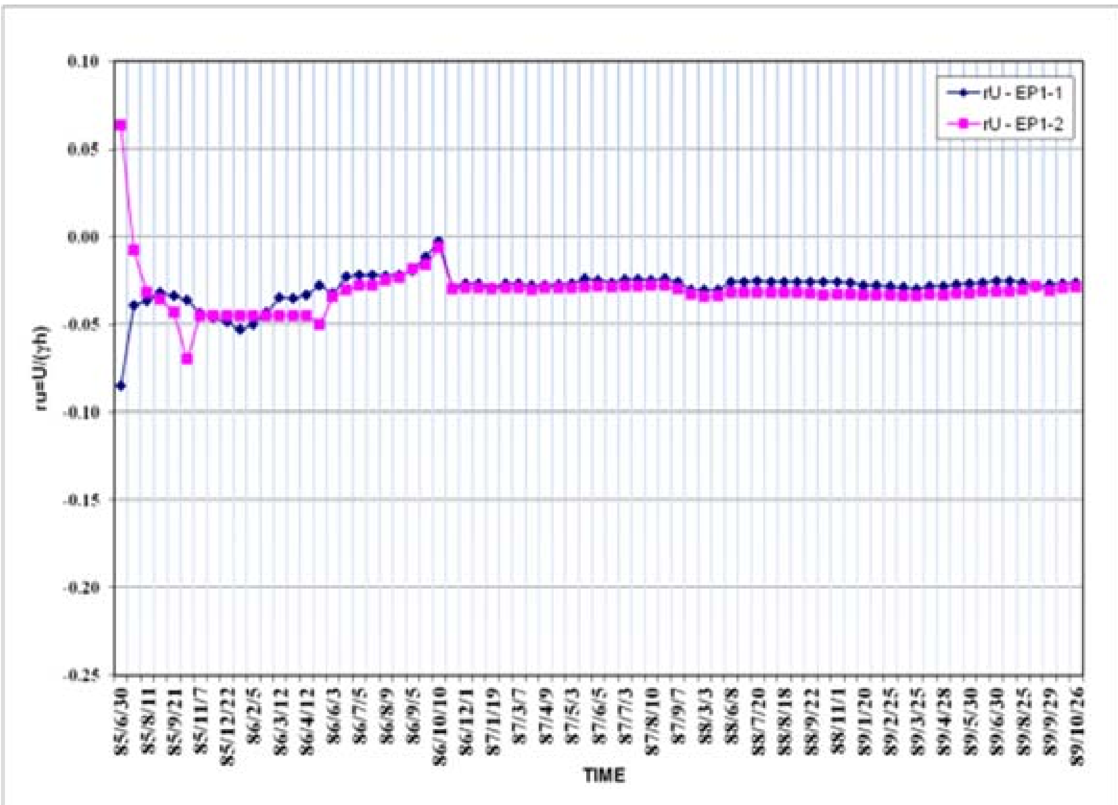

Figure 17. The changes in pore water pressure , section 1-1 at level 1690

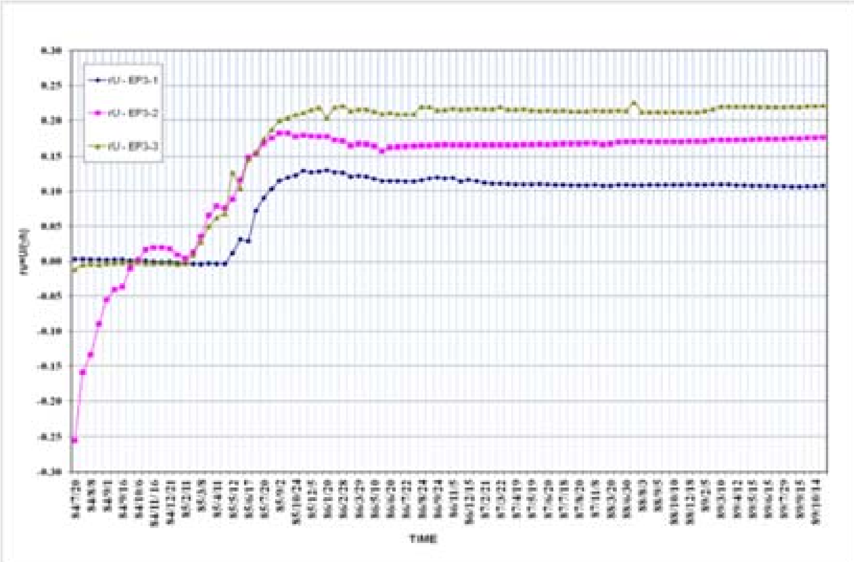

Figure 18. The pore water pressure ratio , section 3-3 at level 1655 and 1690

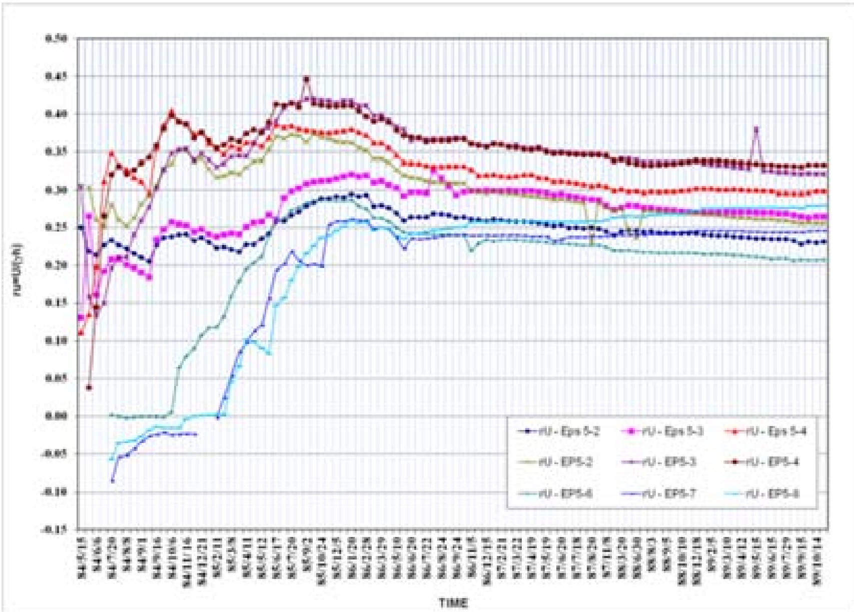

Figure 19. Changes in pore water pressure ratio related to section 5-5 at levels 1630, 1639,1655,1690

Evaluations showed that maximum rate of pore water pressure at different levels are as follow:

Level 1630 meters at section 5 ,0.41- level of 1639 meters at section 5 ,0.45- level 1655meters at sections 3 and 5 ,0.28- level 1657 at section 7 ,0.23- level 1670 at section 6 , 0.57- level 1673 at section 2 and 8 ,0.28 – level 1690 meters at sections 1,3,5 and 7 ,0.17 –level 1695 meters at sections 4,6 and 8 ,0.18.

Considering above data, maximum pore water pressure ratio at Dam's body considering the evaluation of eight transverse sections of Gelabar Dam is related to section 6-6 that its amount is 0.57. For small dams in order to preserve safety, the number of pore water pressure ratio 0.62 can be considered as the maximum limit and for large dams, this ratio can be increased up to 0.7. Considering the domain of pore water pressure ratio for Earth dams, Gelabar Dam is in suitable condition of Hydraulic rapture.

Evaluation of the rate Arching at Gelabar Dam's body

One of the very important issues and capable to review in dams, is Arching. This phenomenon occurs because of the compressibility of the construction materials of the crust and core. Considering that core construction materials are mainly clay and they are due to subsidence, but the core construction materials of granules and have instant subsidence through the time that the core subsidence increases, the core because of high transformation relies on the crust.

To the phenomenon of hanging the core of the crust that causes the decrease in vertical pressure in the core, is called Arching. Maximum Arching generally occurs close to filter, and it is decreased in the middle of the core. If Arching phenomenon it will cause the decrease in tension in the core and there will be the possibility of hydraulic rupture during watering.

To provide a low amount of Arching, Arching ratio is defined that includes: the proportion of vertical pressure at a point of the core on product of core construction materials gravity by embankment height at upper hand of the considered point inside the core (equation 10).

$$Arching\,Ratio = \frac{\sigma_v}{\gamma\, h} \tag{10}$$

It is worth- mentioning that the smaller this ratio is, occurred, the more arching inside the core will be.

Transverse section 5-5

In section 5-5 of a set of considered precise instruments have installed at levels 1639 and 1655. Figures related to the evaluation of Arching ratio during construction and watering Gelabar Dam are included as following :

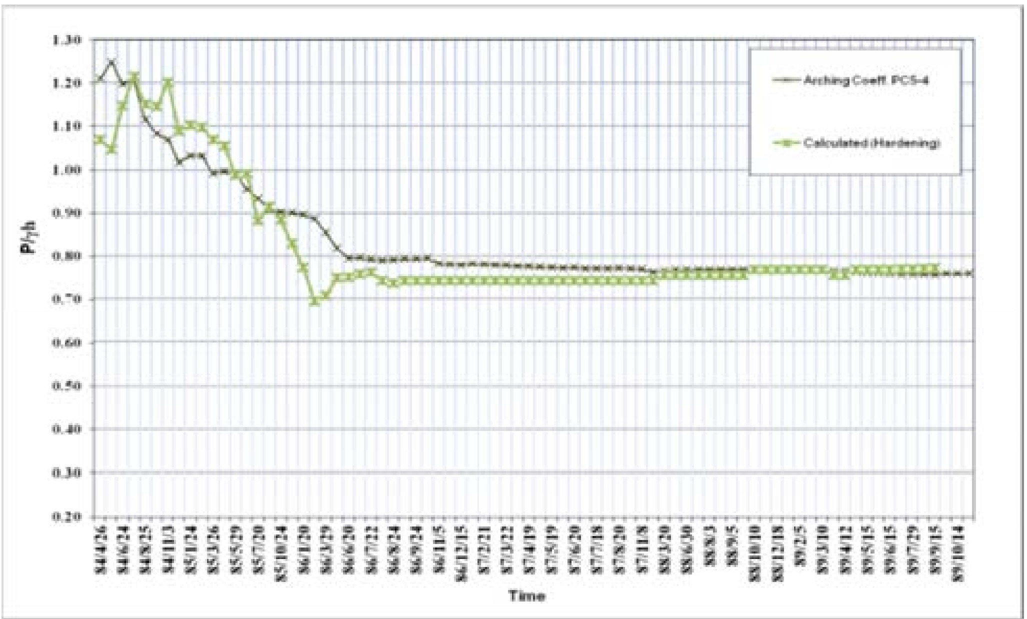

Figure 20. Arching ratio , level1639, upper head the core.

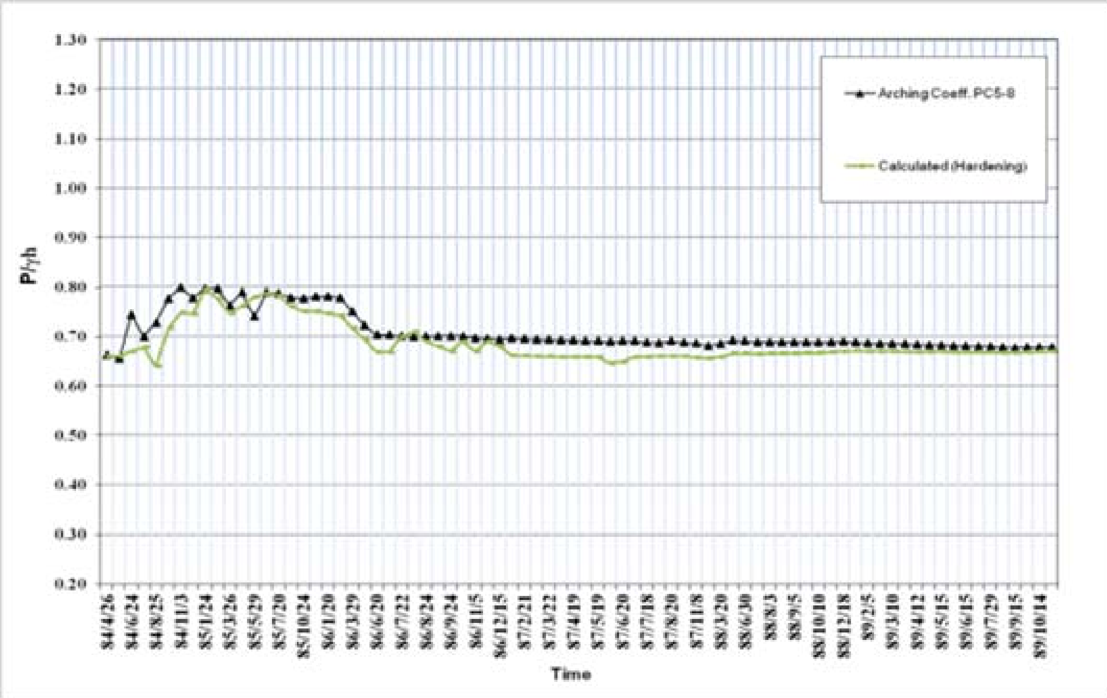

Figure 21. Arching ratio , level 1655, upper head the core

Evaluations show that return analysis software model has the great conformity with precise instruments data that these ratios are in an acceptable domain. Also it is observed return analysis model based on hardening behavior, has the great conformity with the results of precise instruments and it is worth –mentioning that at the start of embankment ,the amount of Arching ratios has had a lot of fluctuations but with continuation of embankment and the increase in the over –head height ,the amount of this ratio has tended to a stable number.

Transverse section 7-7

In section 7-7, set of considered precise instruments installed at level 1657.

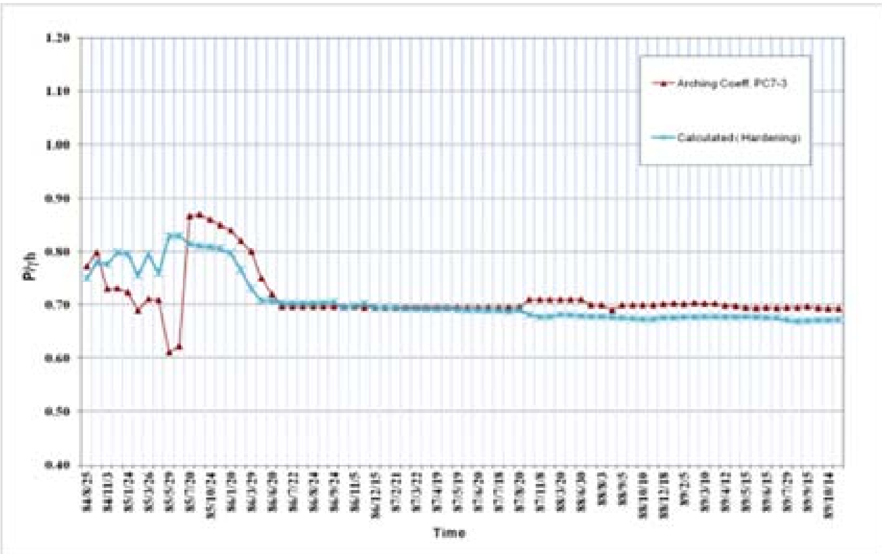

Figure 22. Arching ratio- level 1657- upper hand the core

The features of each set of precise instruments include: five tension gauges and a piezometer that have registered readings from the installation day one to 2020. Figures related to the evaluation of Arching ratio during construction and watering Gelabar Dam has followed below.

Evaluating section 7-7 , it is observed that Arching ratios related level 1657 , is located at intervals from 0.61 to 0.9. Also it is observed that at the start of construction the rate of Arching ratio has had fluctuations, but with continuing embankment and the passage of time, the amount of these ratios have tended towards a stable amount. Comparing ratios obtained with Arching ratios of world ‘s largest dams like: OSWATWAN with 130 meters height in Norway that its Arching ratio is 0.9 to 0.32 and Wattandaquant Dam with 125 meters height that its Arching ration is 0,35 to 0.63 (Niroomand, 1996) and considering that the more the Arching ratio is ,the less the created Arching will be, we reach this conclusion that Gelabar Dam will have no problem regarding hydraulic rupture and Arching phenomenon is less at the core. Observations indicate that maximum Arching related to upper hand of the dam close to filter.

Studying the possibility of hydraulic rupture at Dam’s body

To estimate the risk of hydraulic crack, through the method of comparison of tensions with hydrostatic pressure of water is applied. In this method, a comparison between main tensions, maximum and minimum total tensions, total horizontal and vertical tensions in upper hand of the core with water hydrostatic pressure has been implemented.

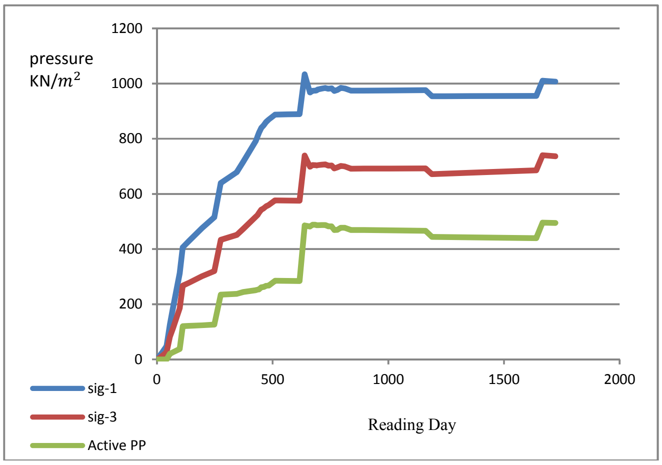

Figure 23. Comparison of main tensions with hydrostatic pressure of water at level 1639.

Reviews show that in different levels of Dam’s body during construction and watering, the amount of tensions has been more than the amount of the amount of hydrostatic pressure. Therefore, the risk of hydraulic crack in Gelbar Dam is not probable.

Evaluation of soil lateral pressure ratio in Dam Body

The proportion of vertical tension that is recognized as soil lateral pressure ratio at inertia and from the equation 11, it is determinable, which has always taken geo-techniques Engineers’ attention.

$$K_0 = \sigma h / \sigma v \qquad (11)$$

One of the equation evaluation methods provided by researchers in order to determine it, is the use of precise instruments’ Data that the real amount of this ratio for the embankments which is gradually created and become dense, is obtained. This ratio is reckonable through having the amounts of horizontal and vertical tensions.

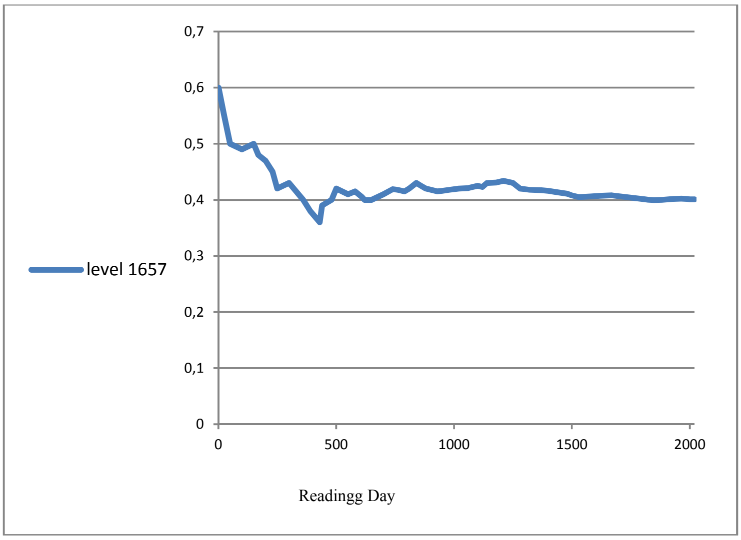

Figure 24. Soil lateral pressure ratio at level 1657

The evaluations show that at the start of embankment, confining tensions are so little, for this reason, the amount of K0 is variable but with the increase the level of embankment and the increase in vertical pressure, the amount of K0 tends towards around K0 = 0.4.

Conclusion

In this research, the limited components of reservoir Dam Gelabar located at Zanjan province, re provided as case study. Accomplished analysis is related construction time and the first watering. Also, by using the information obtained from precise instruments, for Gelabar Dam ; return analysis done with the aid of software Plaxis V8 and geotechnical parameters of Dam's construction materials which are corrected with the aid of return analysis, have been used for remodeling Dam's behavior. Next step, by determining hole water pressure , pore water pressure ratio ; the amount of changes in total tension and effective tension , the rate of Arching and soil lateral pressure at transverse sections of Gelabar Dam , at different levels were evaluated and the possibility of hydraulic rupture and the stability of Gelabar Dam were analyzed.

- The evaluations showed that the obtained results from the hardening model has better conformity with the results precise instruments which are indicator of real soil behavior rather than Mouher –Coulomb model. This issue can be because of using more complete parameters in hardening model.
- Results are indicative that extra pore pressure resulted by reading installed piezometers , in practice has been created inside the core because of relatively large width of clay core , low penetration of granules construction materials and the appropriate density of construction materials, but the project implementation time causes the decay of pore pressure that has created inside the core. Also the maximum hole water pressure ratio in Dam's body considering the evaluation of eight transverse sections of Gelabar Dam are related to section 6-6 that its amount is 0.57. considering the domain of pore water pressure ratio for earth dams , Gelabar Dam is in suitable condition regarding hydraulic rupture.
- Installed piezometers upper hand the clay core, because of river water penetration at upper hand, show larger amounts of hole water pressure than the core center. A large part of this pressure is due to head water at upper hand, so that the piezometer which is located at upper

hand filter , level 1639 meters shows the pressure almost equal to the water height at upper hand .

- Evaluations showed that the amount of total tension has maximum rate at upper hand part that by moving towards the center of the core ,the amount of total tension is decreased while by keeping out of the core center and moving towards lower hand , the amount of total tension increases but still it is less than the total tension at upper hand.
- In Tension gauges installed in 45 degree position , because of hole excavation and placement of the tension gauge in angled position and low amount of soil density inside the hole , Arching phenomenon occurs and as a result precise instruments show less tension than the real tension, also the change in installation degree can be an effective factor in changing the amount of registered tension.
- Evaluation of tension gauges show that total tensions obtained from return analysis in directions x,y,z, have relatively great conformity the results obtained from precise instruments and also on final days of reading because of consolidation phenomenon , the changing procedure in total tension has had a little downturn.
- Main changes of total tension in Dam’s body have occurred during construction operation, this issue, completely reveals the necessity of behavior survey during construction.
- Evaluations showed that at the start of embankment , the limited tensions are so small, for this reason the amount of K0 is variable but with the increase of embankment level and the increase in vertical pressure ,the amount of K0 tends towards a stable amount around K0=0.4.
- Evaluations showed that at different levels of Dam’s body, during construction and watering, the amount of maximum and minimum main tensions have been more than the amounts of water hydrostatic pressure, therefore the risk of hydraulic breakage of Gelabar dam is not probable.
- By the evaluation of different section of Gelabar Dam, it was observed that Arching ratios are between 0.52 to 0.9 which in comparison with Arching ratios of world’s largest dams like: OSWATWAN with 130 meters height in Norway that its Arching ratio is 0.9 to 0.32 and Wattandaquant Dam with 125 meters height that its Arching ration is 0,35 to 0.63 [10], we reach this conclusion that Gelabar Dam will have no problem regarding hydraulic rupture and Arching phenomenon is less at the core and Arching phenomenon in the core is low when Arching related to upper hand has occurred near the filter.
- By return analysis and achieving a model that has had closer behavior to the reality , the points expect those of Precise instrument’s placements ,can be evaluated and the result is that Gelabar Dam’s reliability ratio regarding hydraulic rupture is in suitable condition .
- Present research shows that results obtained from preliminary analysis modeling and data from precise instruments have differences but in secondary modeling (Return Analysis) through changes in effective parameters, model behavior have become close with and has better conformity to precise instrument behavior. In Return analysis model elasticity module and core penetration has been decreased and the core adherence has been increased and also because of cement slurry injection to the foundation, penetration of the foundation is decreased.

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